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Super-Resolution of Long-Wave Infra-Red Imagery for Space Object Identification

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6. AUTHOR(S)

Professor Bobby R. Hunt

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)

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8. PERFORMING ORGANIZATION REPORT NUMBER

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13. ABSTRACT (Maximum 200 words)

The objectives of this research are motivated by the increased number of manmade satellites in orbit about the earth. Surveillance and monitoring of these satellites is a growing mission of the US Air Force. Ground-based telescopes that operate in the visible and near infrared spectrum are the primary system for this surveillance. Thermal infrared images of such satellites provide additional intelligence on the status and capabilities of satellites. However, the resolution of thermal (long-wave) images is poorer, due to the longer wavelengths. This research project seeks to demonstrate the processing of such images to increase the object resolution beyond the diffraction-limited detail implied by the telescope aperture and operating wavelength. Successful achievement of such processing will provide greater mission utility without additional costly telescope upgrades.

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Report on AFOSR Grant # F49620-97-0099.

Super-Resolution of Long-Wave Infra-Red Imagery for Space Object Identification

AFOSR Grant # F49620-97-0099
Progress Report for 1996-97
Principal Investigator: Prof. Bobby R. Hunt

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1. Objectives

The objectives of this research are motivated by the increased number of manmade satellites in orbit about the earth. Surveillance and monitoring of these satellites is a growing mission of the US Air Force. Ground-based telescopes that operate in the visible and near infrared spectrum are the primary system for this surveillance. Thermal infrared images of such satellites provide additional intelligence on the status and capabilities of satellites. However, the resolution of thermal (long-wave) images is poorer, due to the longer wavelengths. This research project seeks to demonstrate the processing of such images to increase the object resolution beyond the diffraction-limited detail implied by the telescope aperture and operating wavelength. Successful achievement of such processing will provide greater mission utility without additional costly telescope upgrades.

2. Status of Effort

During the past year we have made progress in three distinct areas:
(1) theoretical efforts on the foundations and limitations of super-resolution;
(2) practical, applied simulations of long-wave infrared imagery.
(3) development of a new algorithm for recovering information from phase-corrupted pairs of polarized images.

3. Accomplishments

During the past year the investigations of this Grant have resulted in the following accomplishments,

(1) During the past year Prof. Marcellin and Mr. Carl Bauer (graduate student research assistant) developed an initial set of results in the theoretical foundations of super-resolution. The results established, first, that a well-known super-resolution algorithm (often referred to as the Gerchberg algorithm) can be computed in a closed-from version that does not require the iterative method previously promulgated for the solution. The closed form uses the singular value decomposition. Second, they have established an analogy between Error Detection and Correction Codes (EDAC), and

super-resolution and have obtained initial results using the Fourier Transform as extended from the usual definition over the real numbers to more algebraic fields.

(2) Dr. Hunt has used a simple model of a positive compact object to develop a basic theory of the way in which super-resolution actually utilizes information below the cut-off frequency to reconstruct frequencies beyond the cut-off. This model shows that the nature of a positive compact object is such as to always generate spatial frequencies that leave a "signature" throughout the spatial frequency spectrum. A successful super-resolution algorithm uses this information in a fashion that reconciles the information below the cut-off with potential information above the cut-off that gave rise to the lower frequency information.

(3) Prof. Hunt, Dr. David Sheppard (post doctoral student) and Mr. Joe Green (graduate student research assistant) conducted a series of large simulations of satellite images modeled in varying levels of background and with varying levels of turbulence. The levels of background and turbulence were established by the efforts of Dr. Janet Rountree, who used her experience and colleagues in infrared astronomy to obtain estimates of the background and turbulence effects at various wavelengths out to the far-IR region. (Some IR imagery has also been obtained. The imagery at long wavelengths, however, comes from astronomical objects, since no collections of satellite objects at long wavelengths are underway.) These simulations have explored the extent of super-resolution that can be expected, and have also shown that removing the background increases the overall quality of the processing.

(4) Dr. Hunt developed a new algorithm for the recovery of phase information from pairs of polarized images that have been corrupted by atmospheric turbulence. The algorithm uses an optimization model to reconstruct the phase of the corrupted images, and has been demonstrated to be robust in recovering phase data, even in the presence of substantial phase errors.

4. Personnel Supported

The following personnel were supported under the funds of this Grant during the past year (1997-1998):

Principal Investigator: Dr. Bobby R. Hunt, Professor of Electrical & Computer Engineering and Professor of Optical Sciences;

Co-Principal Investigator: Dr. Michael Marcellin, Professor of Electrical & Computer Engineering

Collaborating-Principal Investigator: Dr. Janet Rountree, Research Professor of Electrical & Computer Engineering

Dr. David Sheppard: Post-Doctoral Student in Electrical & Computer Engineering

Mr. Joseph Green: Graduate Research Assistant & PhD Student in Electrical & Computer Engineering

Mr. Carl Bauer: Graduate research Assistant & PhD Student in Applied Mathematics

5.Technical Publications

- Journal Publications

  D. G. Sheppard, B. R. Hunt, and M. W. Marcellin, "Iterative multiframe super-resolution algorithms for atmospheric-turbulence degraded imagery," J. Opt. Soc. Am. A, Vol. 15, No. 4, April 1998, 978-992.

  B. Hunt, T. Overman, P. Gough, "Image reconstruction from pairs of Fourier transform magnitude," *Optics Letters*, vol. 23, pp. 1123-1125, 1998.

  D. O. Walsh, K. G. Bauer, M. W. Marcellin, and B. R. Hunt, "Non-iterative implementation of the Gerchberg algorithm," submitted to J. Opt. Soc. Amer. A.

  K. G. Bauer, M. W. Marcellin, and B. R. Hunt, "Reed-Solomon coders and Super-resolution," in submission to J. Opt. Soc. Amer. A.

- Conference Publications

  K. Panchapakesan, A. Bilgin, D. Sheppard, M Marcellin, B. Hunt, "Simultaneous compression and denoising of imagery using non-linear interpolative vector quantization," Digital Signal Processing Workshop, Bryce, Utah, August, 1998.

  D. Sheppard, B. R. Hunt, "Blind super-resolution of turbulence degraded images," Asilomar Conference on Circuits and Systems, Monterey, CA, November, 1998.

  J. Green, B. R. Hunt, "Improved super-resolution via background removal" Optical Society of America, Annual Meeting, Baltimore, October, 1998.
  IDC99 Papers

6. Interactions / Transitions

- Talks:
  Invited Presentation at Australian Workshop on Propagation and Image Science, December 1997.

- Transitions

  Delivered MATLAB software for phase retrieval from two images to AFRL, Kirtland AFB, Albuquerque, NM.

Delivered MATLAB software for super-resolution from multiple frames of atmospheric turbulence degraded imagery to AFRL, Kirtland AFB, Albuqueruque, NM.

7. Patent Disclosures

None

8. Honors

None

Contact Report

Contact Report for Grant # F49620-97-0099

We have been in direct contact with Air Force Personnel with interests and missions in the general area of this Research Grant. The following are the names of personnel who were involved in discussions during the past year.

Captain Bruce Stribling
USAF AFRL / MSSS / AMOS

Major David Richards, USAF
USAF AFRL / MSSS / AMOS

Dr. Joshua Kann
USAF AFRL / DEX

AF Major Monte Turner, USAF
(Organization: Special Access Required)

Dr. Steve Hadley
(Organization: Special Access Required)